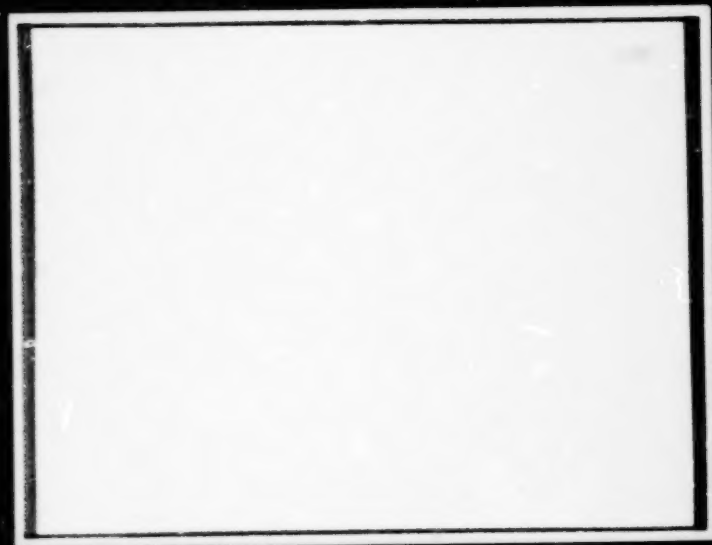


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CREDA

Remote Photovoltaics Applications

CREDA is a program which has been jointly funded by Energy, Mines and Resources, Canada and the Yukon Government, Department of Economic Development. For more information or copies of reports contact the Energy Branch, Yukon Government, Box 2703, Whitehorse, Y1A 2C6, (403) 667-5471.

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Foreword

The availability of secure and affordable energy supplies is a subject of national concern. Our primary energy sources are becoming more costly and less accessible. However, Canada has both the resources and technical expertise needed to develop renewable and alternative sources of energy.

The governments of Yukon and Canada have entered into a Conservation and Renewable Energy Demonstration Agreement as one means of pursuing this end. Cost shared by the territorial and federal governments, CREDA has a budget of \$3.3 million and is dedicated to the development and demonstration of conservation and renewable energy technologies.

The objectives of CREDA are:

- To develop and demonstrate promising new technologies, which, when widely adopted, will exploit renewable resources, conserve energy and/or use energy more efficiently.
- To develop broad public awareness of the potential of renewable energy and conservation technology.
- To provide opportunities for the commercial application of the technologies.
- To create economic spin-off benefits for manufacturing, industry and commerce.
- To create employment in new or existing energy-related industries.

The remote photovoltaics project which is reported on in the following pages is an important attempt to demonstrate that the direct conversion of solar energy into electricity is feasible in remote locations where limited servicing and high levels of reliability are essential.

Executive Summary

The following report examines the technical and economic viability of using photovoltaic cells to power Very High Frequency (VHF) radio transmission repeater stations located on remote mountain top sites. Three sites, two in Yukon and one in Northern British Columbia, were used for the demonstration.

Sites were equipped with two ARCO high efficiency solar modules each containing 35 four inch solar cells capable of 37 watts of peak power, or alternatively, two TPK high efficiency solar modules each containing 36 two inch solar cells.

These powered two CGE mobile radios which were modified for repeater operation. The modifications consisted of the reduction of transmitter power and the interconnection between the transmitter and the receiver. The mobile repeater configuration was in-line rather than the conventional back-to-back.

The solar modules were found to operate efficiently with a duty cycle of five to ten per cent. One site which was in heavier use was found to require an additional solar module to prevent deterioration of signals from peripheral areas.

Peak efficiency of the system was obtained in full sunlight with a surrounding snow cover, in cold temperatures and in association with lead calcium batteries.

The photovoltaic/lead calcium battery system was found to reduce the capital and operational costs of remote communications stations significantly.

Résumé:

Ce rapport examine les possibilités d'emploi de piles photovoltaïques pour faire fonctionner des stations de relais de radiotransmission à très haute fréquence situées sur des sommets montagneux isolés. Trois sites furent choisis pour cette démonstration, deux au Yukon et un au nord de la Colombie Britannique.

Ces sites étaient équipés de deux modules solaires ARCO à haut rendement contenant chacune 35 cellules solaires de quatre pouces capables d'une puissance de pointe de 37 watts, ou, alternativement, de deux modules solaires TPK contenant chacune 36 cellules solaires de deux pouces.

Celles-ci faisaient fonctionner deux postes de radio portatifs qui avaient été modifiés pour l'opération de relais. Les modifications consistaient à réduire la puissance du transmetteur et à relier le transmetteur et le récepteur. La disposition du répéteur portatif était en alignement au lieu du dos à dos habituel.

On a trouvé que les modules solaires fonctionnaient bien avec un facteur d'utilisation de cinq à dix pour cent. Un des sites étant soumis à un usage plus poussé, nous avons dû y ajouter une module solaire pour empêcher la détérioration des signaux en provenance des régions périphériques.

Le rendement maximum du système a été obtenu en plein soleil, les alentours étant recouverts de neige, par des températures froides et en relation avec des accumulateurs au plomb-calcium.

Le système d'accumulateurs photovoltaïques au plomb-calcium a été reconnu capable de réduire le coût d'immobilisation et d'exploitation d'une façon significative.

Introduction

Total North Communications Limited, in conjunction with the Canada/Yukon Conservation and Renewable Energy Demonstration Program tested photovoltaics as a potential renewable resource for use with three VHF mountain top repeaters and related equipment.

Total North Communications Limited (TNC) is a Whitehorse company formed in 1972. The company's first major contract involved designing and installing a VHF system for the Yukon Government.

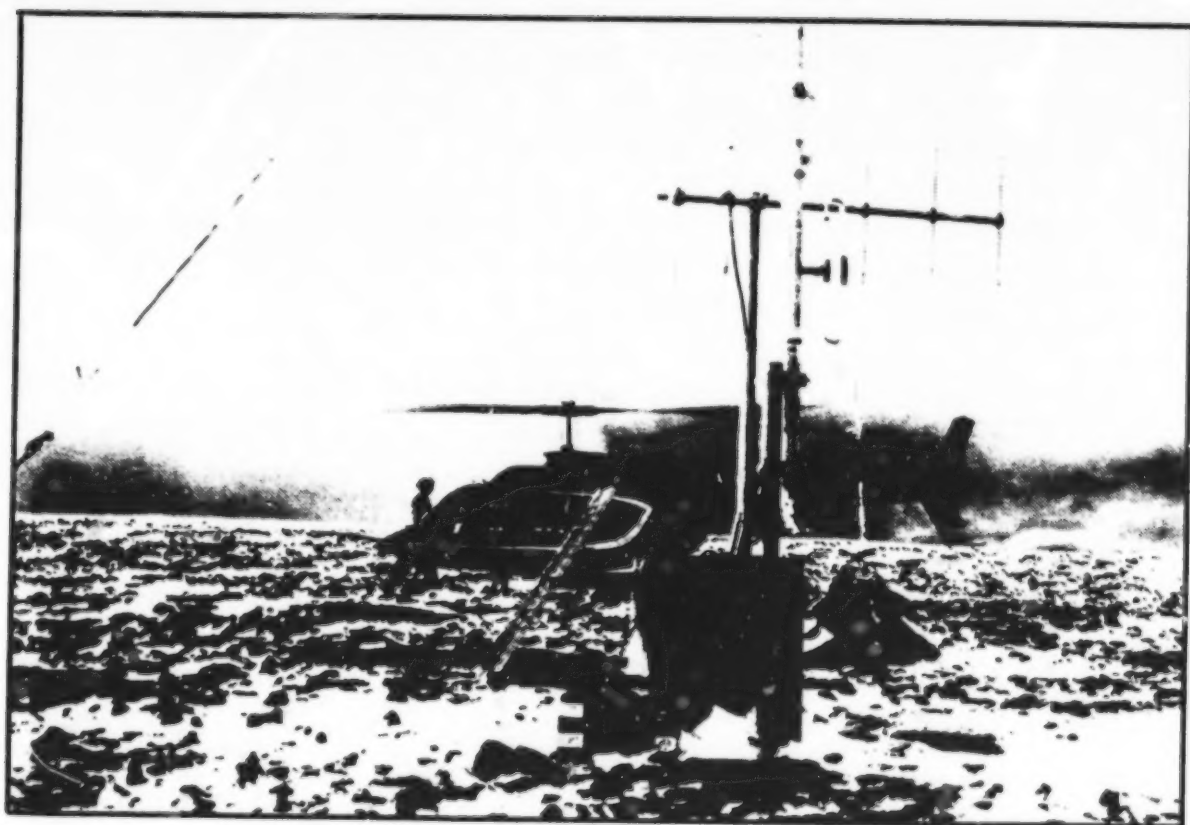
The Department of Highways, Government of Yukon was faced with the problems of communicating over very large distances. The technology of the day was HF. Because this technology relied on bouncing transmissions off the ionosphere, the system was vulnerable to variations in sun spot activity and weather, and as a consequence was subject to inconsistent performance.

Yukon's severe winter and the attenuated terrestrial communication links demanded a more reliable system if only for reasons of safety.

The Yukon Government was one of the first jurisdictions to establish a VHF system which relies on line-of-sight transmissions. but the first generation technology is not without its limitations, even though it is a good, workable system. The problems are concerned mostly with powering and servicing the system.

Since the installation of this VHF system TNC has expanded into a wide range of communications applications, many of them in remote locations. In these remote applications TNC had previously used large capacity, lead acid batteries and "swapped out" the batteries once every two to three weeks. The battery changes were expensive as access to the sites was by helicopter only. Each battery change cost \$400 to \$600.

Conversion of photovoltaics as a charging system for the batteries offered the hope that the helicopter trips would virtually be eliminated.



Initial Testing

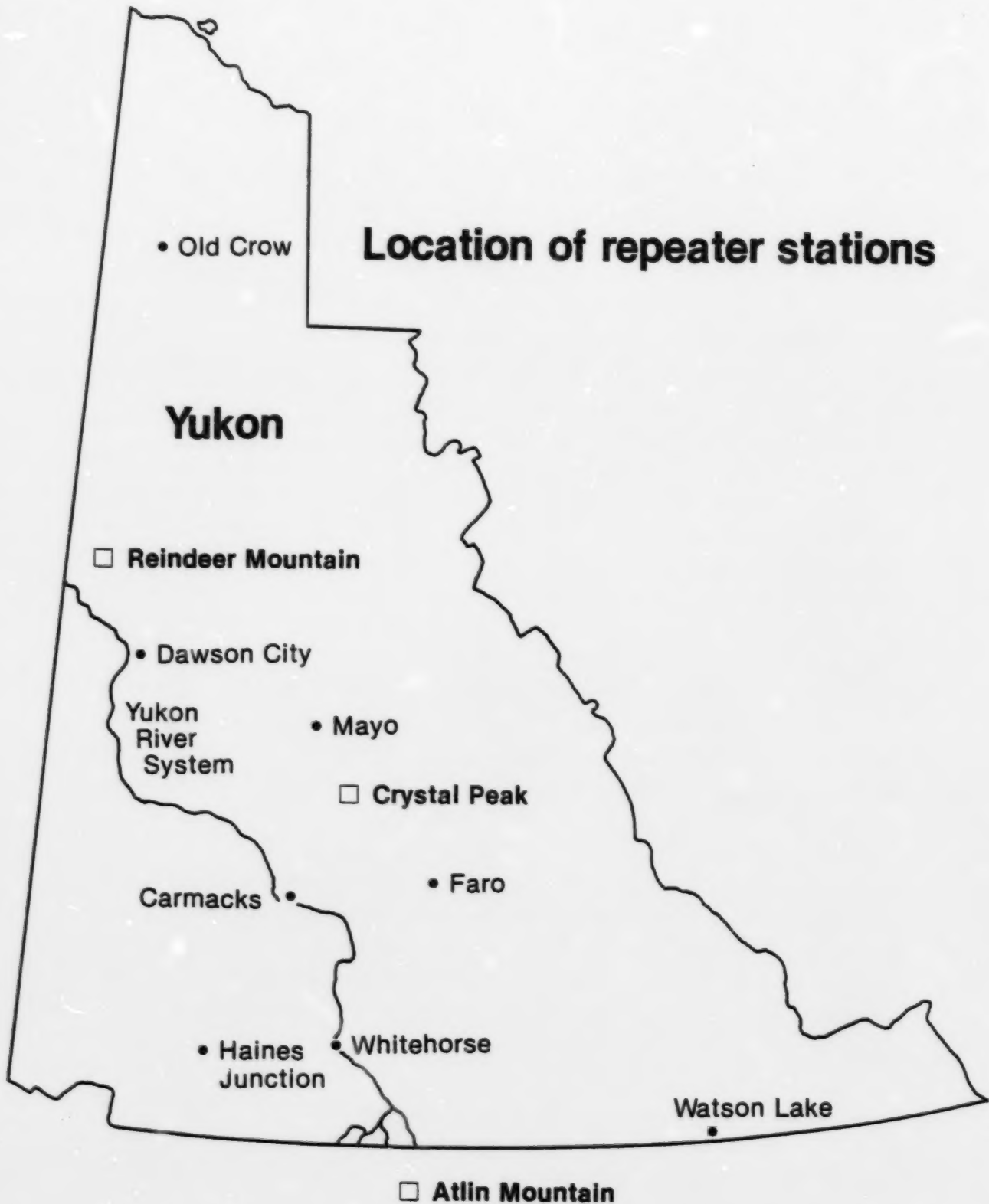
Stage I consisted largely of a familiarization period with the panels and a "dry-run" at the Total North shop located in Whitehorse. Two Arco Panels were mounted on the roof at Total North in late February, 1982. The two panels were connected to a battery which powered a VHF mountain top repeater. The repeater was set up in a back-to-back configuration operating through North West Telephone's Radio telephone repeater. The power source for the repeater was a lead/acid Cat Battery of a 240 amp hour rating. Both the electronics and battery were located in a weatherproof enclosure outside Total North's building.

The initial testing period - late February to April 1982 indicated that the panels would supply enough power to keep the battery at an acceptable level. A case of self fulfilling expectations comes into play here. TNC personnel looked for what they wanted to see, which was the panels could produce enough power to operate the systems as envisaged but they ignored several other important variables which would come into play later. The first point was the amount of power produced from the panels. As they were to learn later the spring time tests were conducted under the most ideal conditions. The combination of sunny weather, relatively cool temperatures and increased light from snow reflection all assured the panels produced at maximum.

The power generated by the panels seemed adequate to run the mountain top repeater systems. The estimates were based on a rough calculation of a 5 - 10 per cent duty cycle (the repeater would be active 5 - 10 per cent of a day, and at rest for the remaining 95 - 100 per cent of the day), and the experience that a 240 amp hour battery lasted 2 - 3 weeks, (based on the previous year's repeater installations).

If a 240 amp hour battery lasted 2 weeks at an absolute minimum, 24 amp hours per day would be required. Some safety margin would also be necessary as it would not be desirable to reduce the battery to less than one half its rated output (i.e., 120 amp hours).

Location of repeater stations



Location

Three sites were used during the demonstration and a description of each follows.

(1) Dawson City Area $139^{\circ} 25' \text{ W. } 63^{\circ} 27' \text{ N.}$

A "local drop" VHF transceiver was located on Reindeer Mountain, 60 miles north west of Dawson City. The repeater was used for point to point communications for gold mining and commercial concerns in the Klondike placer area. The repeater and photovoltaics were located at the 5000' level. Active season was from May to early November.

(2) Crystal Peak $134^{\circ} 30' \text{ W. } 62^{\circ} 57' \text{ N}$

"Back to back" and "local drop" repeaters were located on Crystal Peak. The repeaters were used for a mining exploration concern and provided point to point communications and interconnection to the telephone system. The equipment was located at the 6,500' level, 65 miles east of Pelly Crossing.

(3) Atlin $133^{\circ} 50' \text{ W. } 59^{\circ} 20' \text{ N}$

A "back to back" system provided placer miners in the Atlin area with access to the telephone system via the repeater. Equipment was located on Atlin mountain at the 6000' level.

Actual Experience

The field trials of the systems demonstrated beyond doubt that photovoltaics are a cost effective alternative to the method which had been employed earlier. On one system (Atlin) no visits were required for either service or battery changes. On the other two systems, the local drop repeater was visited twice - once certainly for a battery change - the second time the batteries were changed by other than TNC personnel and as such TNC was unable to ascertain whether the problem was due to batteries or an intermittent connector found on a subsequent trip. The third repeater (back-to-back and local drop) definitely was underpowered and a third panel was added to the system.

In terms of direct savings a reasonable estimate of costs saved would be 15 helicopter trips @1.0 hrs/trip x \$400 or \$6,000. In fact without photovoltaics the projects probably would not have been undertaken.

Performance

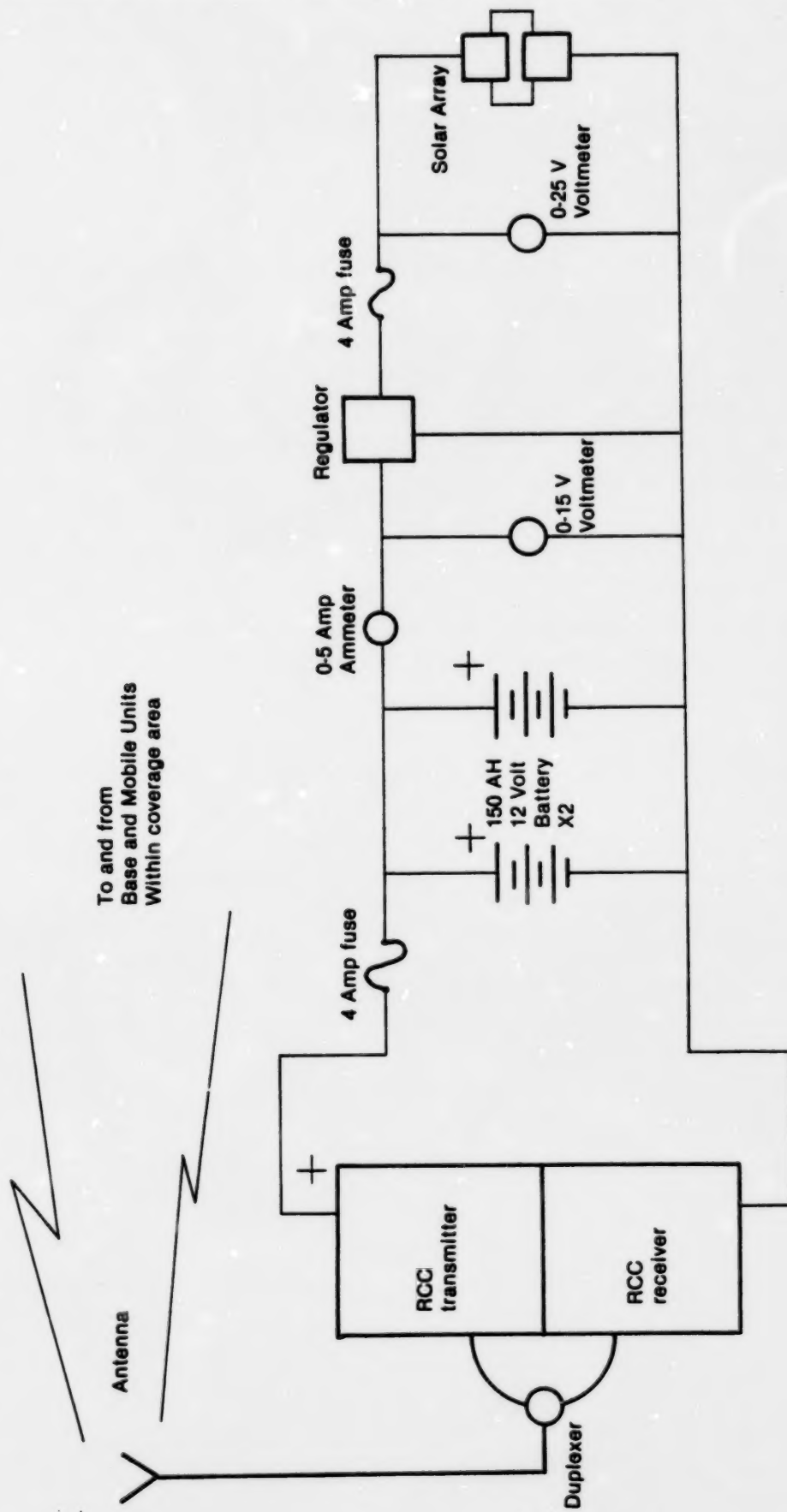
In order to gain maximum coverage from the repeaters, all equipment was located on the vantage point of each of the mountains. The equipment, photovoltaics included, was therefore subjected to a very hostile environment. Extreme winds, snow and ice loading, and temperatures ranging from $+30^{\circ}\text{C}$ to -40°C were common to all sites. A special enclosure (a box constructed of $3/4$ " plywood laminated with fiberglass) was used to house the electronics and batteries. The photovoltaics (panels) were attached to the enclosure by an angle iron and originally mounted directly to the side of the housing via angle iron brackets.

The mounting arrangement was entirely suitable in terms of wind loading and ease of installation, however, the mounts proved unsatisfactory for snow and ice conditions. The main problem encountered was the snow and ice which collected on the panel during the low or no light hours. When melting occurred, snow and ice which built up on the panels would slide off in sheets gathering at the bottom of the panels. The low portion of the panels would remain obscured, degrading the cells' ability to produce electricity. With a snow covering of 1.5 cm the panels were approximately half as efficient as when they were totally clear. The solution to the problem is a mount which allows a free space between the panels and the ground equal to maximum snow depth plus $1\frac{1}{2}$ times the panel height. This allows the snow and ice build up to fall freely from the panel.

Panel Operation

Two types of panels were used in testing. The American-manufactured Arco 2300 panels and the Canadian TPK panels. Both panels were absolutely reliable. The panels produced electricity consistently during their tenure and displayed no signs of deterioration either physically or in terms of performance. With proper installation techniques (blocking diode regulators, proper wiring) based on TNC observation, there is no reason to expect any failures from the panels.

The Arco panel was considerably more efficient than the TPK delivering an average 1/6 to 1/3 more electricity under like conditions. The efficiency of the Arco can be related to cell size. The Arco panel used four inch diameter cells the TPK cells were two inches in diameter. The larger size cell gives a greater density hence greater efficiency. Subsequent to the testing, a panel using square cells has been developed by Solarex Inc. This panel has even greater density than the Arco panel and is slightly more efficient. The Solarex panel is being tried by Forestry in the Yukon and to date is operating up to expectation. (Appendix II)



**Dawson City Restricted Common Carrier
To provide Point to Point
communications throughout coverage area.**

Weather/Panel Operation

The testing period for the panels was from mid April to late October. While clinical data on panel output was impossible to collect, it was possible to gain a feel for panel production in a variety of meteorological conditions. The panels optimum output was achieved in full sunlight with a surrounding snow covering. The reflection from the snow seemed to have the effect of increasing the light to the panel and lower temperatures further increased the efficiency of the panels.

Output during summer was relatively stable varying with weather conditions. Location proved somewhat of a problem in the fall as the high locations received very little direct sunlight. The heavy use system (Dawson) did fail in the fall as a result of three weeks of inclement weather.

Batteries

TNC originally used lead acid batteries. However, after one season it became clear lead acid batteries were not the most appropriate storage medium for a photovoltaics system. Clinically the amp hour rating should have sufficed but in the field the charge given by the solar panels and the operating characteristics of the lead acid batteries lead to deterioration of system performance. This was particularly evidenced by the local drop system in Dawson. The usage on the system was much higher than expected. At the peak of the operating season there were 35 radios operating through the repeater and at times users of the system were standing by waiting for free air time. In terms of duty cycle, it is almost impossible to state a figure as usage was more a function of peak periods as opposed to a continuous duty cycle. Suffice to say that the demands on the system were much greater than a 10% duty cycle.

The deterioration was noted in a number of fringe areas. Radios operating close to threshold began to drop off. If, for instance, the batteries started to drop below the nominal 12 volt rating the repeater would still function but at a reduced output (i.e., 4.5 watts as opposed to 5 watts). Radios close to the repeater would function normally, but radios with a poorer signal would start to lose their signal.

The lead acid batteries did not have the ability to handle the discharge/charge cycle consistent with a photovoltaic system. Once the batteries dropped below a critical voltage ($\frac{1}{2}$ rated output) the batteries did not recover no matter what kind of charge was applied (batteries were taken from the system and placed on a 110 volt charger but still did not come up to rated capacity).

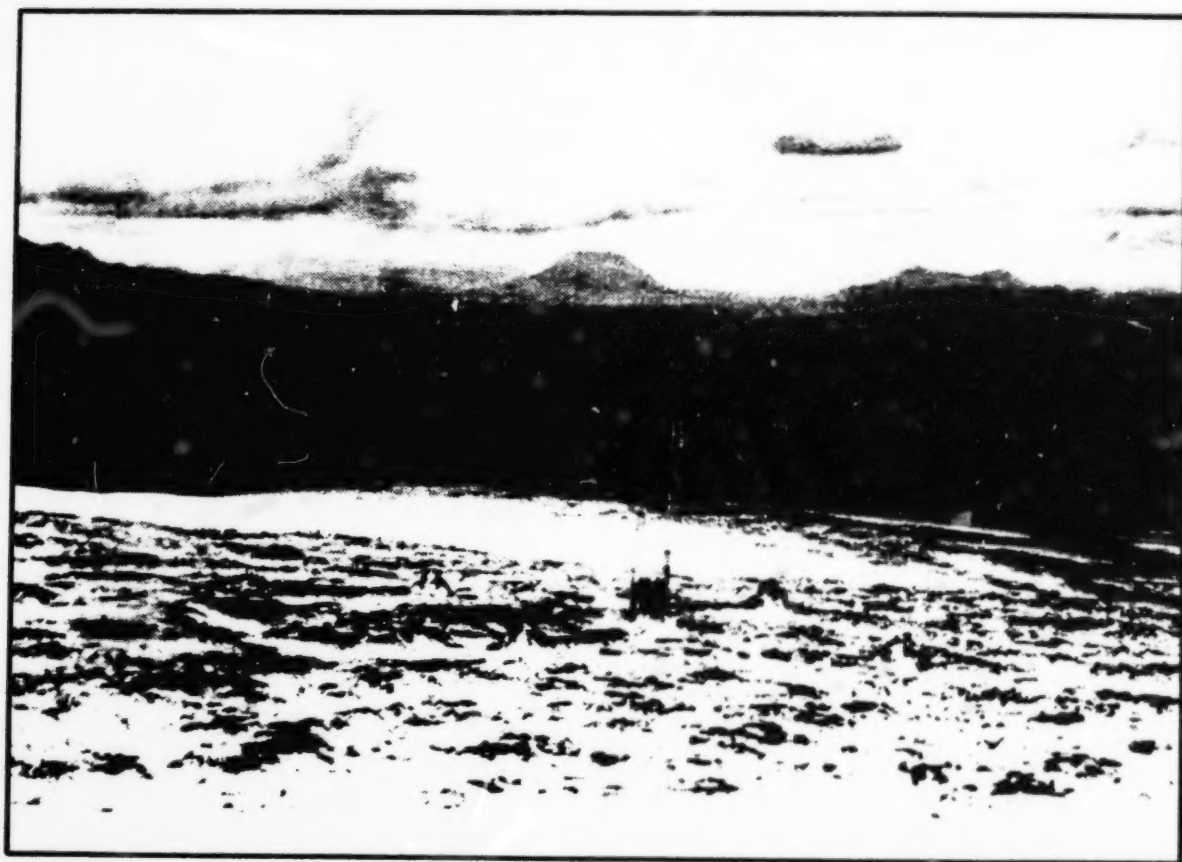
The lead acid batteries were replaced with lead calcium batteries. The lead calcium batteries had several distinct advantages:

- (1) Safety - the Pb. Ca. batteries are a sealed unit - no dangerous gases are produced and no corrosive acid is present.

- (2) performance - the Pb. Ca. batteries are much better suited to the charge/discharge cycle associated with a photovoltaic system. Whereas the lead acid batteries are theoretically good for 10 charge/discharge cycles, the lead calcium batteries are good for 100 charge/discharge cycles. Field experience bears this relationship out. A further advantage of the Pb. Ca. batteries is their cold weather performance. The electrolyte in a lead acid battery can freeze potentially destroying the battery - this is a problem not present with the lead calcium battery.

Budget Review

<u>Budget to Actual</u>	<u>Budget</u>	<u>Actual</u>
Photovoltaic panels	\$4,669.00	\$4,669.00
Regulators	1,224.00	1,224.00
Miscellaneous hardware	280.50	830.00
Labour	2,860.00	3,510.00
Monitoring & reporting	910.00	910.00
 Additional cost		
Replacement batteries		855.00
(lead calcium)		
Freight		130.00
 Total	\$9,943.50	\$12,128.00



Cost and Economic Benefits

The cost effectiveness of the photovoltaic system is best analyzed in relation to location and usage rather than a strict dollars per kilowatt relationship. For example, a small portable generator would produce "cheaper" power in terms of dollars per kilowatt but a small generator does not have the capability of turning on and off remotely (without major modification), requires maintenance and is not as reliable as a photovoltaic system. For a remote location such as TNC's application, the portable generator is not a feasible alternative. In a cabin or remote location which has active human access the economics are somewhat altered. The small generator is more cost effective as the turn-on/turn-off function can be monitored and acted upon. The solar panels' viability comes into play when the production of power is examined from an aesthetics and reliability perspective. The solar panels are without question a very favourable method in terms of pollution, noise, fossil fuel consumption, etc. Environmentally the panels are free of hazards. In terms of reliability, over a long time span (5 years, plus) the panels have a definite edge on a portable generator set-up. While the panels produce according to the vicissitudes of the weather conditions they will produce with a great reliability - any time there is daylight some power will be produced - if a generator breaks down, no power whatsoever will be produced. The load demands (hence, backup storage) required of a photovoltaic system are of critical importance in evaluating a generator set versus photovoltaic system and to a large degree how much weight is placed on the aesthetic concerns versus short term economic considerations.

In TNC's particular application the cost effectiveness of the system was demonstrable. TNC originally made helicopter trips to swap out batteries which had been depleted after 2-3 weeks use. With the photovoltaics, the trips for power related problems were brought to 1 per season. In dollar savings this amounted to 16 hours of helicopter time @\$400 per hour or \$6,400.

Energy Impacts

The direct energy impacts of photovoltaics are minimal. No single system will replace very much fossil fuel. However, the indirect impact is far greater since the applications for this study are in remote locations. To reiterate a point made earlier, the problems associated with VHF transmission are those of powering and servicing. It is the servicing which consumes the greater amount of energy and it is here that photovoltaics will have some measureable impact on energy consumption.

However, the nature of the study, its objectives and its financial restrictions preclude a discussion, with verifiable and quantitative data, into these indirect energy impacts. It is a legitimate topic of study but remains outside the scope of this demonstration.

Potential Target Audience

Photovoltaic cells have been on the market for a number of years and despite initial expectations there has not been a price breakthrough. The capital costs have lowered in that time but the barrier to marketability is still price and not technology. Long range drops in price are probable but it remains unlikely that the drops will be sudden and will open up huge markets. Industry spokesmen feel the growth in the market will proceed gradually as the price drops.

Thus far photovoltaics have filled a void in the area of what might be termed unique installations - satellites, ocean buoys, remote repeater stations. There remain, however, many applications in this area which can be met by photovoltaics.

The following is the result of a survey of possible Yukon applications:

Remote Meteorological Data Collection

At present a wide variety of meteorological data collection devices are in use in Yukon. Included among these are automatic temperature gauges and 14 long term precipitation gauges which are run on batteries. The results of the Total North study are not relevant to the equipment in use since the study concerns itself with mountain-top locations. Weather collection data devices are generally found in Yukon's valleys. More information concerning the performance of photovoltaic cells in these locations is needed.

Northwest Telephone

Northwest Telephone is currently running 17 sites in the two territories and northern British Columbia which are not connected to electrical grids. Of these, three are using propane fired generators and the remaining 14 utilize caustic potash batteries. Each location is referred to as a complete redundancy site having two radios and two generators. Each radio requires 55 watts.

The NorthwTel sites have some resemblances to the TNC sites but there is one major difference, the duty cycle. NorthwTel technicians explain they require a 100 per cent duty cycle either because a site demands it, or in some cases where there is a diminished duty cycle there is great variation and at times 100 percent is needed.

Forest Resources, Department of Indian and Northern Development

Photovoltaic cells have been in use for five years in this branch of DIAND. At present they are used in six repeater stations and in two lookout towers. They plan to install photovoltaic cells in one more repeater station and five more lookout towers next year leaving eight lookout towers and ten repeaters still on battery.

Unlike Total North's applications, Forest Resources personnel point out that the advantage for them is not in the expense of transportation. They list, among the advantages of solar cells: they are less expensive than batteries; they are quiet and clean; their maintenance, particularly on the repeater stations is down; they become more efficient in the cold; they have a 20 to 25 year life span compared to four to five for batteries; overall power costs are down 20 - 25 per cent.

There were two other points noted by the Forest Resources spokesperson. Caustic potash batteries are considered dangerous to carry by helicopter pilots who fear the results of a split battery and the chemical reaction between the battery's components and the aircraft's aluminum. The second point made was an anecdotal comment concerning an experiment in the summer of 1983 with a station on top of the Dome in Dawson. They found with the sun just over the northern horizon at midnight, the cells still provided a 10 per cent charge, even though the sun was directly behind the panels.

Timberline TV

Timberline TV operates five mountain top translator stations. Each transmitter requires only 5 watts. The drawbacks for applying photovoltaics are mainly two: normal checks and breakdowns not related to the power source make frequent trips to the stations necessary therefore there would be no saving in helicopter expenses; the transmitters require AC power units. The spokesman for Timberline TV thought this fact alone would prohibit the use of photovoltaics.

Government of Yukon

The viability of solar has been amply demonstrated for at least 8 months of the year. With the use of lead calcium batteries it would seem entirely possible to engineer a system comprised of a combination of photovoltaics cells and lead calcium batteries which would prove cost effective for use on the Yukon Government VHF system. In terms of rough calculations the present cripel batteries produce 4,000 amp/hrs through a life of 3 years (the batteries have lasted longer but system usage has increased).

$$\frac{4,000}{3 \times 365 \times 24} = \frac{4,000}{26,280} = .15 \text{ amp hour or } 3.6 \text{ amp hr/day}$$

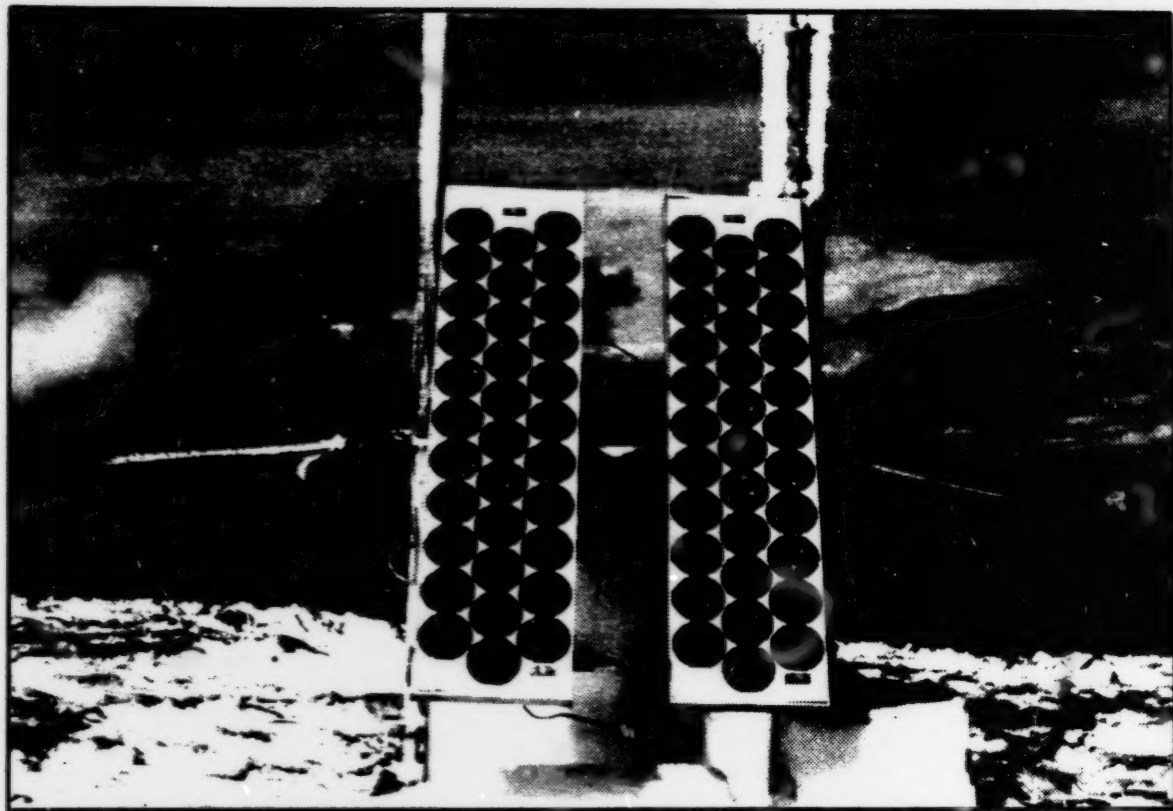
A combination two panels charge and six 120 amp hour batteries would provide adequate power over the hundred day winter period when the sun is at minimum:

@ PANELS AT AVERAGE 4.5 - 5 hours sunlight per day produce easily
 2.5 - 4.0 amp hours/day = 250 - 400 amp hrs per 100 days.
 system drain is 360 amp hours reserve
 = battery strength + p.v. output - draw
 = (360 + 250) - 360
 = 250 amp hours.

Capital cost also compares favourably

	Photovoltaics	Caustic Potash Batteries
32 batteries @ \$150 ea		\$4,800
6 batteries @ 130 ea	\$ 780	
p.v. system	2,700	
misc. mounting	<u>250</u>	<u>3,730</u>
	\$3,730	\$8,530

The system design is presently under review by both ARCO and AC Delco and initial results look promising.



Conclusions

The Total North project was a success within the prescribed limitations of the study. It demonstrated the feasibility of using photovoltaics in isolated situations when a limited duty cycle is required. Competing against conventional battery systems it offers more reliability, cheaper operation and maintenance, longer life and better performance in cold weather. It is, in addition a safer system than caustic potash batteries.

The Total North project, however, also points out the need for more research into applications requiring longer duty cycles, more power and in areas less exposed to continuous direct sunlight.



Energy, Mines and
Resources Canada

Energie, Mines et
Ressources Canada



FINAL PROJECT SUMMARY

Remote Photovoltaics

Canada/Yukon Conservation and Renewable Energy Demonstration Program

Project No. 3766-4-13	Date: November 1, 1983	Sectors: All sectors
Project Locations: Various remote mountain locations	Technology: Solar	Jurisdiction: Yukon
Project Manager: Gordon Duncan	Status: Completed	

Purpose:

To use solar Photovoltaic cells to power VHF communication stations in remote locations in Yukon.

Description:

Two solar photovoltaic panels provide power to storage batteries which in turn are used to operate mountaintop VHF repeater stations with a low duty cycle.

Contributors:

Applicant	\$5344
Canada/Yukon	6629
	\$11,973

Expected Benefits :

1. Frequent servicing trips to replace caustic potash batteries are eliminated.
2. Photovoltaics in remote locations can reduce capital and operational costs of micro scale applications and provide a reliable source of power.

For More Information Contact:

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311 Black Street
Whitehorse, Yukon
668-5175

Robert E. Collins
Energy Branch
Department of Economic Development
Box 2703, Whitehorse
667-5471

Project Costs:

Capital	
Installation	\$ 7,708
Total Installed Cost	3,510
Monitoring and technology transfer	11,218
	2,030
TOTAL DEMONSTRATION COST	<u>\$13,248</u>

Operating Costs:

Pre-demonstration annual cost (helicopter time)	\$ 7,600
Post-demonstration annual cost (helicopter time)	1,200
Net annual savings	6,400

Simple payback Because of the costs involved these applications would not have been undertaken without the photovoltaics as a source of power.

Monitoring:

Initial testing was done in Whitehorse. Information obtained from these tests indicated the number of panels needed at each location. Since the photovoltaic panels were used to repeat radio signals, field monitoring was necessary only when the equipment failed.

Technical Details:

At the three sites two or three photovoltaic panels were used to effect retransmission of radio signals. The panels tested were ARCO 2300 and TPK. Both systems were reliable. Originally the panels were connected to lead acid battery systems but these were found to be unsuitable to the charge/discharge characteristics of photovoltaics. The batteries were changed to a lead calcium system which had ten times the potential for charge/discharge cycles.

Conclusions:

Within the prescribed limitations of the study this project was a success. It demonstrated the feasibility of using photovoltaics in isolated situations when a limited duty cycle is required. Competing against conventional battery systems it offers more reliability, cheaper operation and maintenance, longer life and better performance in cold weather. Optimum performance was obtained in cold weather with full sunlight and surrounding snow cover.
